US009178629B2

(12) **United States Patent**
El-Hassan et al.

(10) **Patent No.: US 9,178,629 B2**
(45) **Date of Patent: Nov. 3, 2015**

(54) **NON-SYNCHRONIZED RADIO-FREQUENCY TESTING**

(75) Inventors: **Wassim El-Hassan**, San Jose, CA (US); **Vishwanath Venkataraman**, San Francisco, CA (US)

(73) Assignee: **Apple Inc.**, Cupertino, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1105 days.

(21) Appl. No.: **13/218,027**

(22) Filed: **Aug. 25, 2011**

(65) **Prior Publication Data**

US 2013/0049786 A1 Feb. 28, 2013

(51) **Int. Cl.**

H04B 17/00	(2015.01)
H04B 17/309	(2015.01)
H04B 17/318	(2015.01)
H04B 17/327	(2015.01)
H04B 17/336	(2015.01)

(52) **U.S. Cl.**

CPC ***H04B 17/0085*** (2013.01); ***H04B 17/309*** (2015.01); *H04B 17/318* (2015.01); *H04B 17/327* (2015.01); *H04B 17/336* (2015.01)

(58) **Field of Classification Search**

CPC H04W 24/00; H04W 56/00; H04W 48/08; H04W 4/06; H04W 52/0216; H04W 52/50; H04W 72/0446; H04W 8/005; H04W 24/08; H04L 43/50; H04L 12/2697; H04L 41/22; H04L 43/18; H04L 65/80; H04L 1/243; H04L 43/0847; H04L 43/106; H04L 12/24

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,807,644	B2	10/2004	Reis et al.	
2004/0082297	A1	4/2004	Stambaugh et al.	
2006/0009160	A1 *	1/2006	Craig	455/67.11
2006/0040654	A1	2/2006	Moore et al.	
2006/0229018	A1	10/2006	Mlinarsky et al.	
2009/0124250	A1 *	5/2009	Topaltzas et al.	455/423
2010/0113011	A1	5/2010	Gregg et al.	
2011/0103235	A1	5/2011	Luong et al.	
2011/0292809	A1 *	12/2011	Olgaard et al.	370/241

OTHER PUBLICATIONS

Gregg et al., U.S. Appl. No. 13/044,844, filed Mar. 10, 2011.

* cited by examiner

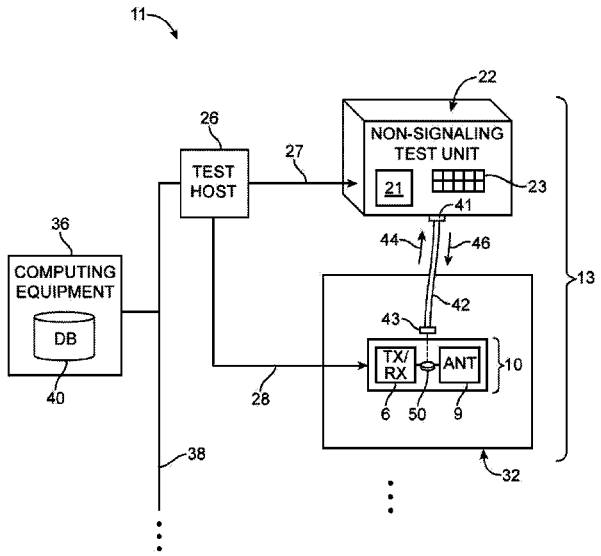
Primary Examiner — Golam Sorowar

(74) *Attorney, Agent, or Firm* — Treyz Law Group; Jason Tsai; Joseph F. Guihan

(57) **ABSTRACT**

A device under test (DUT) may be tested using a test station having a test host, a non-signaling tester, and a test cell. During testing, the DUT may be placed within the test cell, and the DUT may be coupled to the test host and the tester. In one suitable arrangement, the DUT may be loaded with a predetermined test sequence. The predetermined test sequence may configure the DUT to transmit test signals using different network access technologies without synchronizing with the tester. The tester may receive corresponding test signals and perform desired radio-frequency measurements. In another suitable arrangement, the tester may be loaded with the predetermined test sequence. The predetermined test sequence may configure the tester to generate test signals using different network access technologies without establishing a protocol-compliant data link with the DUT. The DUT may receive corresponding test signals and compute receive signal quality.

20 Claims, 6 Drawing Sheets



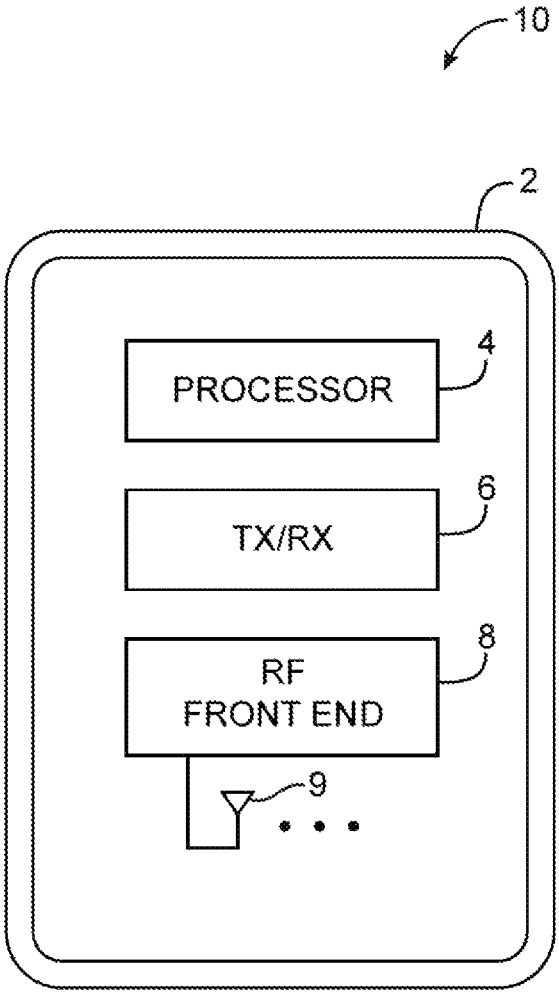


FIG. 1

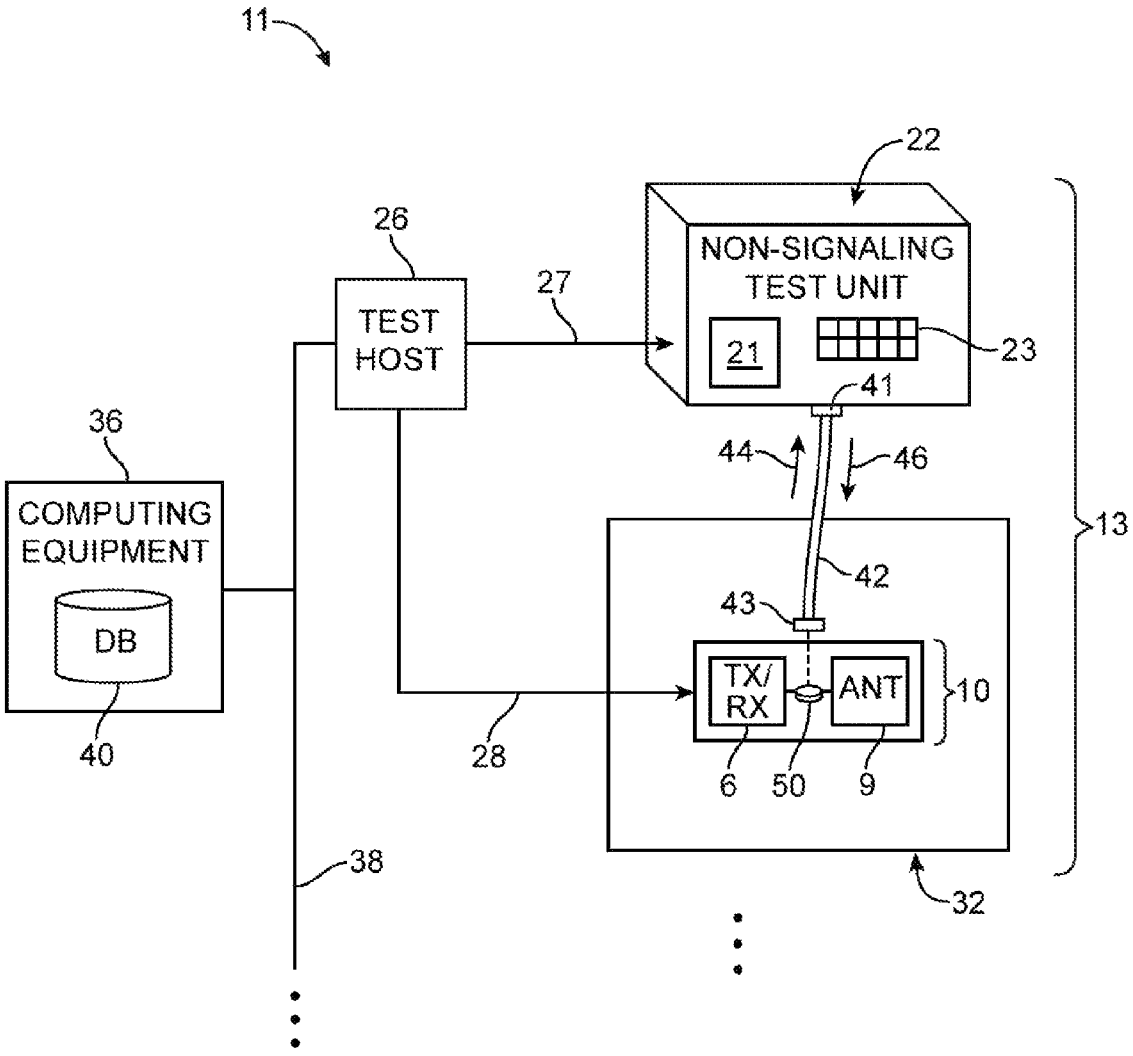
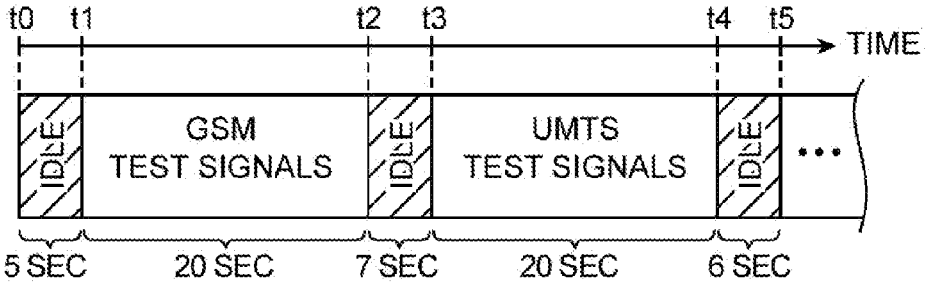

11
22
NON-SIGNALING
TEST UNIT
21
23
41
26
TEST
HOST
27
36
COMPUTING
EQUIPMENT
DB
40
44
46
13
42
43
TX/
RX
ANT
10
6
50
9
28
38
32

FIG. 2



(PRIOR ART)

FIG. 3

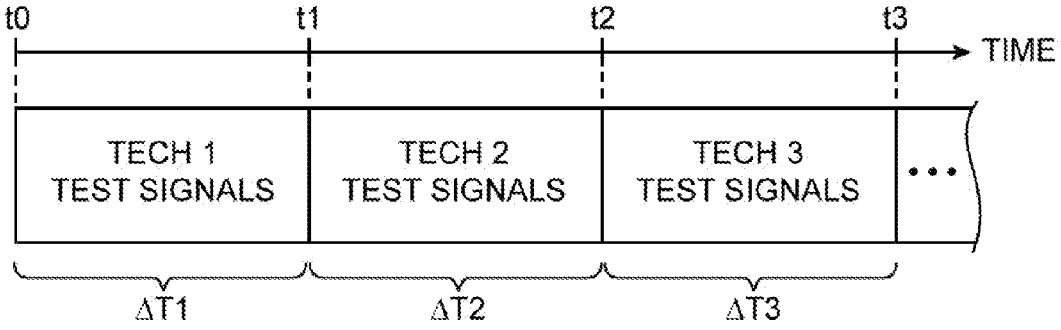


FIG. 4

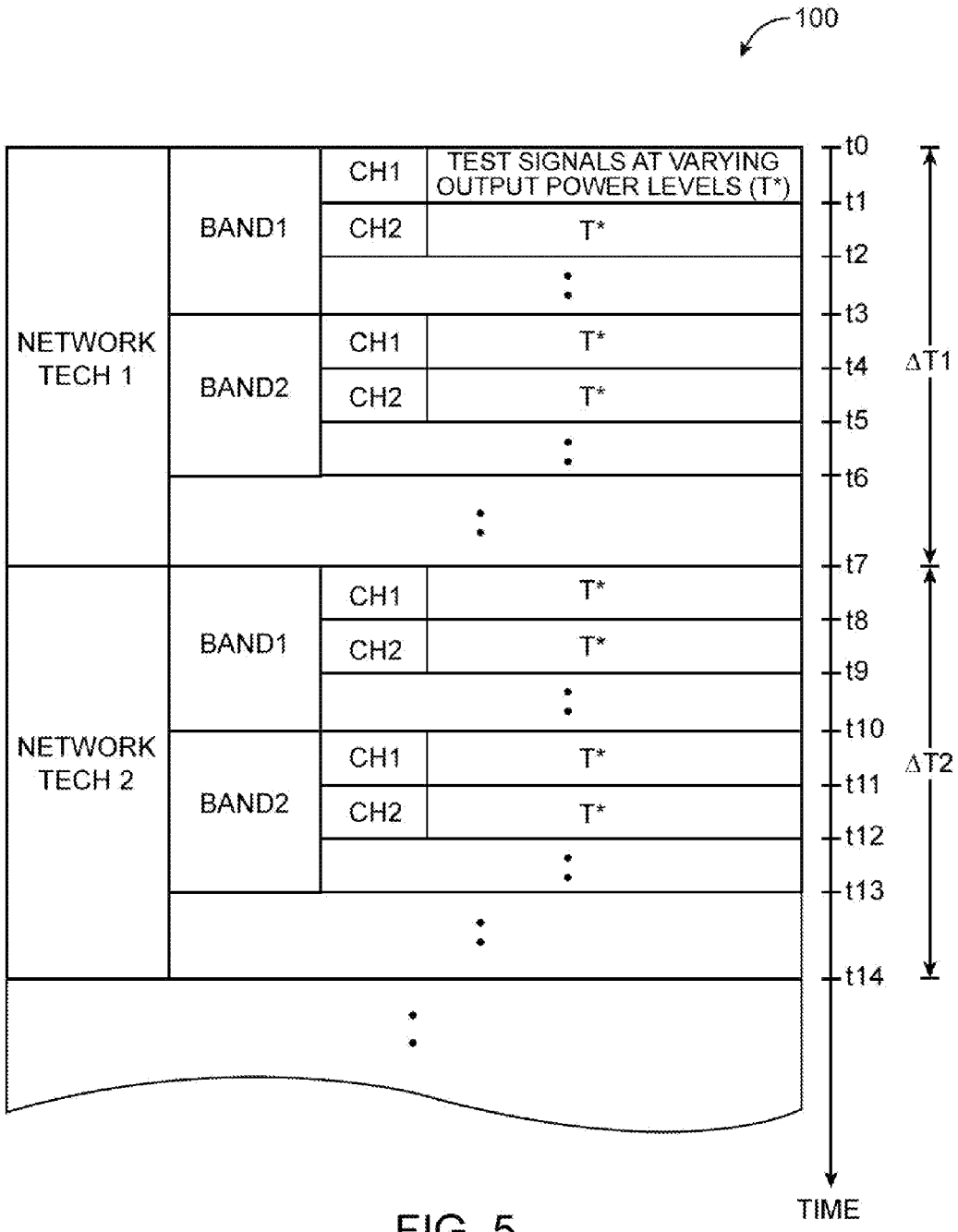

100
NETWORK TECH 1
BAND1
CH1
TEST SIGNALS AT VARYING OUTPUT POWER LEVELS (T*)
CH2
T*
BAND2
CH1
T*
CH2
T*
NETWORK TECH 2
BAND1
CH1
T*
CH2
T*
BAND2
CH1
T*
CH2
T*
t0
t1
t2
t3
t4
t5
t6
t7
t8
t9
t10
t11
t12
t13
t14
ΔT1
ΔT2
TIME

FIG. 5

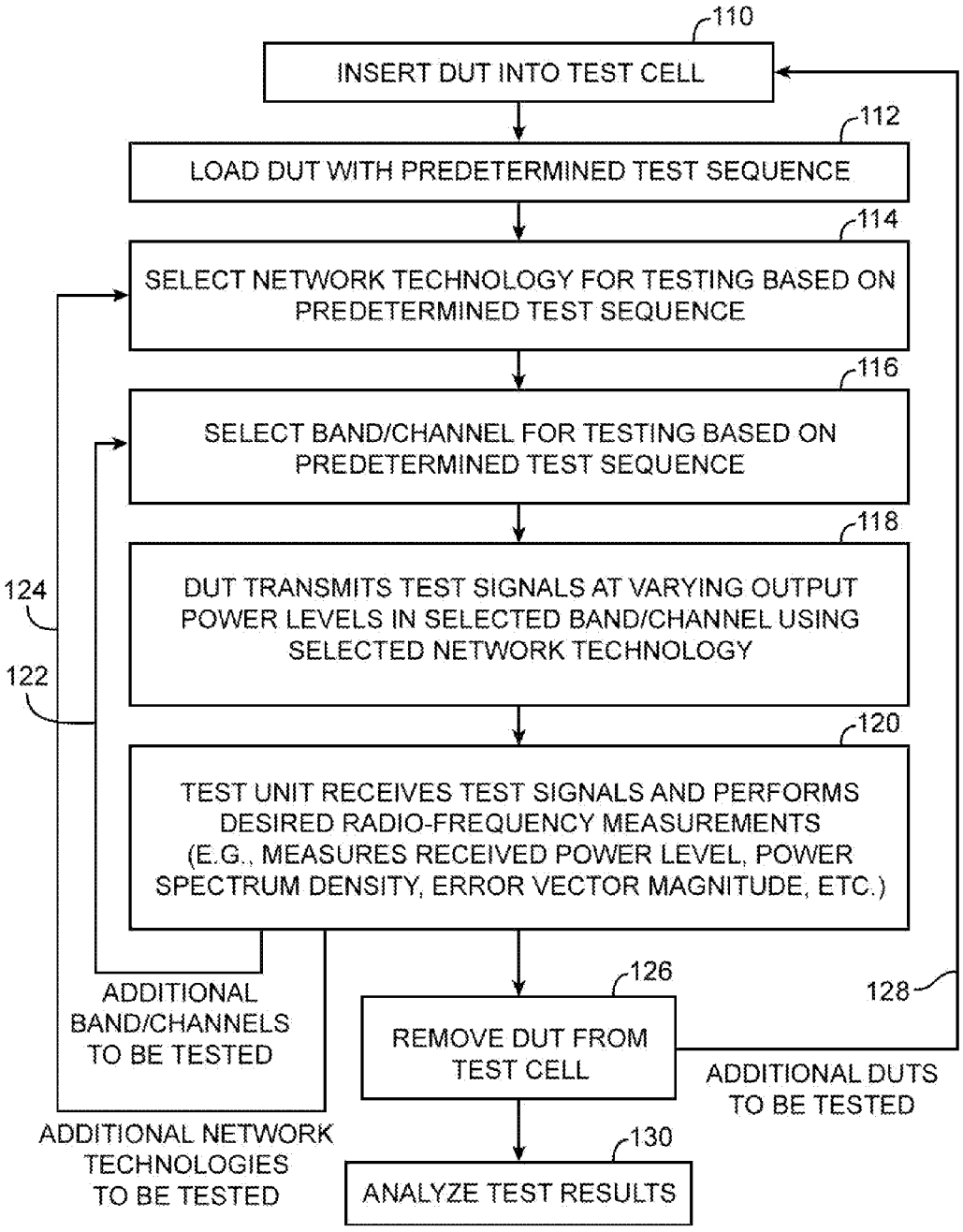

110
INSERT DUT INTO TEST CELL
112
LOAD DUT WITH PREDETERMINED TEST SEQUENCE
114
SELECT NETWORK TECHNOLOGY FOR TESTING BASED ON PREDETERMINED TEST SEQUENCE
116
SELECT BAND/CHANNEL FOR TESTING BASED ON PREDETERMINED TEST SEQUENCE
118
DUT TRANSMITS TEST SIGNALS AT VARYING OUTPUT POWER LEVELS IN SELECTED BAND/CHANNEL USING SELECTED NETWORK TECHNOLOGY
120
TEST UNIT RECEIVES TEST SIGNALS AND PERFORMS DESIRED RADIO-FREQUENCY MEASUREMENTS (E.G., MEASURES RECEIVED POWER LEVEL, POWER SPECTRUM DENSITY, ERROR VECTOR MAGNITUDE, ETC.)
124
122
ADDITIONAL BAND/CHANNELS TO BE TESTED
ADDITIONAL NETWORK TECHNOLOGIES TO BE TESTED
126
REMOVE DUT FROM TEST CELL
128
ADDITIONAL DUTS TO BE TESTED
130
ANALYZE TEST RESULTS

FIG. 6

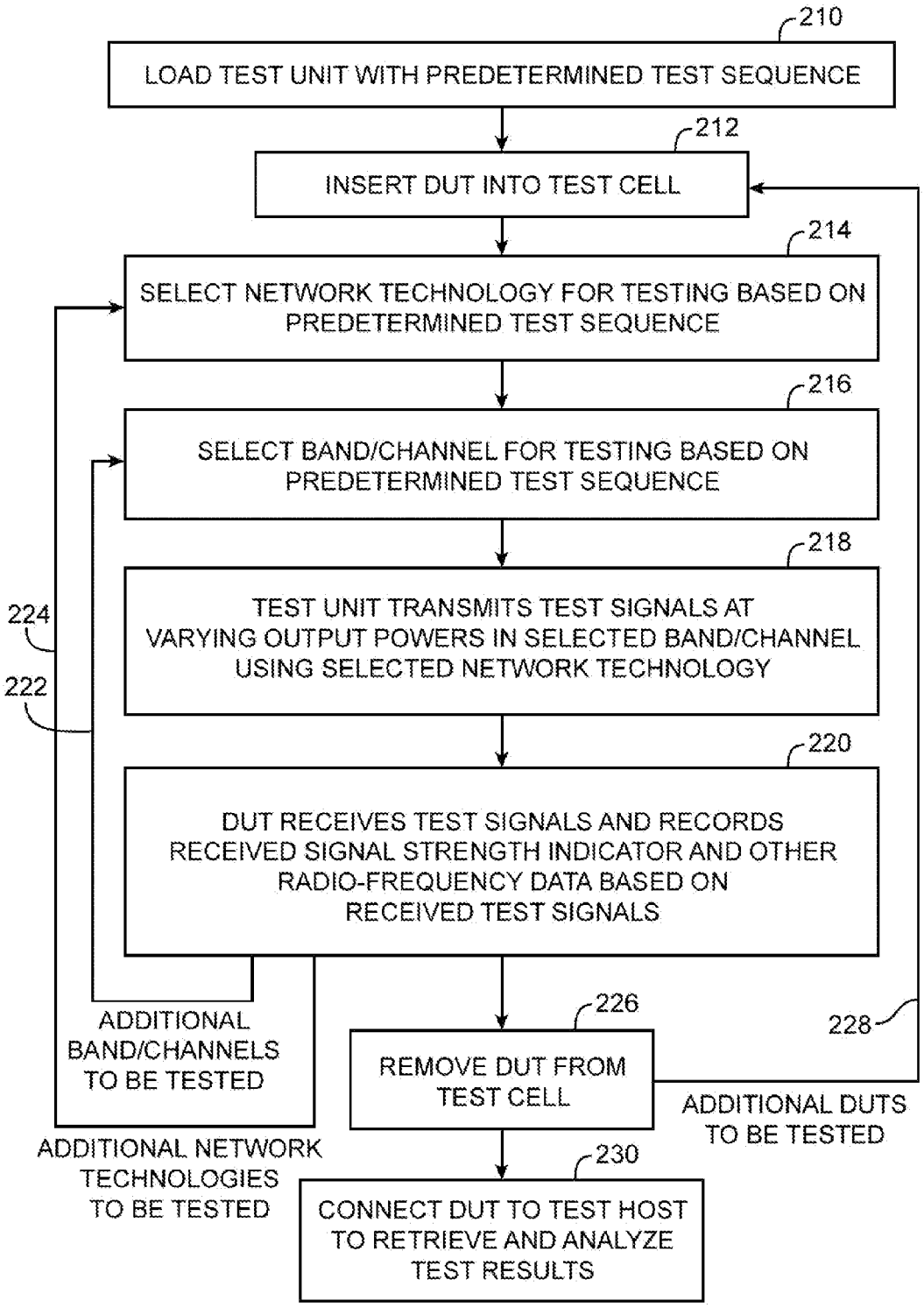

210
LOAD TEST UNIT WITH PREDETERMINED TEST SEQUENCE
212
INSERT DUT INTO TEST CELL
214
SELECT NETWORK TECHNOLOGY FOR TESTING BASED ON PREDETERMINED TEST SEQUENCE
216
SELECT BAND/CHANNEL FOR TESTING BASED ON PREDETERMINED TEST SEQUENCE
218
TEST UNIT TRANSMITS TEST SIGNALS AT VARYING OUTPUT POWERS IN SELECTED BAND/CHANNEL USING SELECTED NETWORK TECHNOLOGY
220
DUT RECEIVES TEST SIGNALS AND RECORDS RECEIVED SIGNAL STRENGTH INDICATOR AND OTHER RADIO-FREQUENCY DATA BASED ON RECEIVED TEST SIGNALS
224
222
ADDITIONAL BAND/CHANNELS TO BE TESTED
ADDITIONAL NETWORK TECHNOLOGIES TO BE TESTED
226
REMOVE DUT FROM TEST CELL
228
ADDITIONAL DUTS TO BE TESTED
230
CONNECT DUT TO TEST HOST TO RETRIEVE AND ANALYZE TEST RESULTS

FIG. 7

NON-SYNCHRONIZED RADIO-FREQUENCY TESTING

BACKGROUND

This relates generally to wireless electronic devices and, more particularly, to testing of wireless electronic devices.

Wireless electronic devices typically include transceiver circuitry, antenna circuitry, and other radio-frequency circuitry that provide wireless communications capabilities. During testing, wireless electronic devices under test (DUTs) can exhibit different performance levels. For example, each wireless DUT in a group of DUTs can exhibit its own output power level, gain, frequency response, efficiency, linearity, dynamic range, downlink sensitivity, etc.

The performance of a wireless DUT can be measured using a radio-frequency (RF) test station. A radio-frequency test station typically includes a test host, a tester (i.e., a signal generator), and a test cell. The signal generator is connected to the test host. Connected in this way, the test host configures the signal generator to transmit downlink radio-frequency signals during test operations.

In conventional radio-frequency test arrangements, a wireless DUT having, for example, a cellular telephone transceiver is placed into the test cell. The DUT is connected to the test host via a control cable or a wireless waveguide or antenna system. A protocol-compliant communications link is established between the signal generator and the DUT (i.e., an active telephone call is established between the signal generator and the cellular telephone transceiver). Protocol-compliant testing has a tendency to drop calls between the DUT and tester when the tester output power level falls below the DUT's downlink sensitivity. Reestablishing the protocol-compliant connection in order to complete testing can add significant time and cost to the test process.

It would therefore be desirable to be able to provide ways for performing non-protocol-compliant testing.

SUMMARY

Test stations in a radio-frequency test system can be used to perform radio-frequency testing on wireless devices under test (DUTs). Each test station may include a test host, a tester (e.g., a signal generator and a power meter), and a test cell. The DUT may be placed within the test cell during testing. The operation of the tester and the DUT may be controlled by commands generated by the test host via control cables. Radio-frequency test signals may be conveyed between the tester and the DUT via a radio-frequency cable.

In one suitable embodiment of the present invention, the DUT may be loaded with a predetermined test sequence (or list). The predetermined test sequence may configured the DUT to send radio-frequency test signals using different communications network access technologies to the tester without having to establish a protocol-compliant link and without synchronizing with the tester. For example, the DUT may be configured to output first test signals at various transmit power levels at desired frequencies using a first network access technology (e.g., the DUT may be configured to transmit test signals in the "2G" Global System for Mobile Communications cellular telephone bands) during a first time period, to output second test signals at various transmit power levels at desired frequencies using a second network access technology (e.g., the DUT may be configured to transmit test signals in the "2G" Code Division Multiple Access cellular telephone bands) during a second time period immediately following the first time period, etc. The tester may receive the corresponding test signals and make desired test measurements on the test signals.

In another suitable embodiment of the present invention, the tester may be loaded with a predetermined test sequence (or list). The predetermined test sequence may configured the tester to send radio-frequency test signals using different communications network access technologies to the DUT without having to establish a protocol-compliant link and without synchronizing with the DUT. For example, the tester may be configured to output first test signals at various transmit power levels at desired frequencies using a first network access technology (e.g., the tester may be configured to transmit test signals in the "3G" Universal Mobile Telecommunications System (UMTS) cellular telephone bands) during a first time period, to output second test signals at various transmit power levels at desired frequencies using a second network access technology (e.g., the tester may be configured to transmit test signals in the "3G" Code Division Multiple Access 2000 (CDMA 2000) cellular telephone bands) during a second time period immediately following the first time period, to output third test signals at various transmit power levels at desired frequencies using a third network access technology (e.g., the tester may be configured to transmit test signals in the "4G" Long Term Evolution (LTE) cellular telephone bands) during a third time period immediately following the second time period, etc. The DUT may receive the corresponding test signals and compute desired signal quality measurements.

Further features of the present invention, its nature and various advantages will be more apparent from the accompanying drawings and the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram of an illustrative wireless device under test with radio-frequency circuitry in accordance with an embodiment of the present invention.

FIG. **2** is a diagram of an illustrative test station that includes a test host, a test unit, and a test cell in accordance with an embodiment of the present invention.

FIG. **3** is a timing diagram showing testing of different cellular network access technologies based on conventional test methods.

FIG. **4** is a timing diagram illustrating testing of different network access technologies in accordance with an embodiment of the present invention.

FIG. **5** is a diagram of an illustrative predetermined test sequence in accordance with an embodiment of the present invention.

FIGS. **6** and **7** are flow charts of illustrative steps involved in testing wireless electronic devices using a predetermined test sequence of the type shown in FIG. **5** in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

Wireless electronic devices include antenna and transceiver circuitry that support wireless communications. Examples of wireless electronic devices include desktop computers, computer monitors, computer monitors containing embedded computers, wireless computer cards, wireless adapters, televisions, set-top boxes, gaming consoles, routers, or other electronic equipment. Examples of portable wireless electronic devices include laptop computers, tablet computers, handheld computers, cellular telephones, media players,

and small devices such as wrist-watch devices, pendant devices, headphone and earpiece devices, and other miniature devices.

Devices such as these are often provided with wireless communications capabilities. For example, electronic devices may use long-range wireless communications circuitry such as cellular telephone circuitry to communicate using cellular telephone bands at 850 MHz, 900 MHz, 1800 MHz, and 1900 MHz (e.g., the main Global System for Mobile Communications or GSM cellular telephone bands). Long-range wireless communications circuitry may also handle the 2100 MHz band.

Electronic devices may use short-range wireless communications circuitry such as wireless local area network (WLAN) circuitry to handle communications with nearby equipment. For example, electronic devices may communicate using the WiFi® (IEEE 802.11) bands at 2.4 GHz and 5 GHz and the Bluetooth® band at 2.4 GHz. It is sometimes desirable to receive satellite navigation system signals such as signals from the Global Positioning System (GPS). Electronic devices may therefore be provided with circuitry for receiving satellite navigation signals such as GPS signals at 1575 MHz.

In testing environments, the wireless electronic devices are sometimes referred to as devices under test (DUTs). FIG. **1** shows an example of a test device such as DUT **10**. DUT **10** may be a portable electronic device, a cellular telephone, a computer, a multimedia device, or other electronic equipment. DUT **10** may have a device housing such as housing **2** that forms a case for its associated components.

DUT **10** may have storage and processing circuitry such as storage and processing circuitry **4**. Storage and processing circuitry **4** may include storage such as hard disk drive storage, nonvolatile memory (e.g., flash memory or other electrically-programmable-read-only memory configured to form a solid state drive), volatile memory (e.g., static or dynamic random-access-memory), etc. Processing circuitry in storage and processing circuitry **4** may be used to control the operation of device **10**. This processing circuitry may be based on one or more microprocessors, microcontrollers, digital signal processors, application specific integrated circuits, etc.

Storage and processing circuitry **4** may interact with a transceiver circuit such as transceiver circuit **6**. Transceiver circuit **6** may include an analog-to-digital converter (ADC), a digital-to-analog converter (DAC), a digital down-converter (DDC), and a digital up-converter (DUC).

In a scenario in which DUT **10** is transmitting, circuitry **4** may provide digital data (e.g., baseband signals) to the DUC. The DUC may convert or modulate the baseband digital signals to an intermediate frequency (IF). The IF digital signals may be fed to the DAC to convert the IF digital signals to IF analog signals. The IF analog signals may then be fed to an RF front end such as RF front end **8**.

When DUT **10** is receiving wireless signals, RF front end **8** may provide incoming IF analog signals to the ADC. The ADC may convert the incoming IF analog signals to incoming IF digital signals. The incoming IF digital signals may then be fed to the DDC. The DDC may convert the incoming IF digital signals to incoming baseband digital signals. The incoming baseband digital signals may then be provided to circuitry **4** for further processing. Transceiver circuit **6** may either up-convert baseband signals to IF signals or down-convert IF signals to baseband signals. Transceiver block **6** may therefore sometimes be referred to as an IF stage.

RF front end **8** may include circuitry that couples transceiver block **6** to one or more antenna such as antenna **9**. RF front end **8** may include circuitry such as matching circuits, band-pass filters, mixers, low noise amplifier circuitry, power amplifier circuitry, etc. Circuitry **4**, transceiver block **6**, RF front end **8**, and antenna **9** may be housed within housing **2**.

In the scenario in which DUT **10** is transmitting, RF front end **8** may up-convert the IF analog signals from transceiver block **6** to RF analog signals (e.g., the RF signals typically have higher frequencies than the IF signals). The RF analog signals may be fed to antenna **9** for broadcast. If desired, more than one antenna may be used in DUT **10**.

In the scenario in which DUT **10** is receiving wireless signals, antenna **9** may receive incoming RF analog signals from a broadcasting device such as a base transceiver station, network access point, etc. The incoming RF analog signals may be fed to RF front end **8**. RF front end **8** may down-convert the incoming RF analog signals to IF analog signals. The IF analog signals may then be fed to transceiver circuit **6** for further data processing.

Examples of cellular network access technologies that may be supported by the wireless circuitry of device **10** include: the Global System for Mobile Communications (GSM) "2G" cellular telephone standard, the Evolution-Data Optimized (EVDO) cellular telephone standard, the "3G" Universal Mobile Telecommunications System (UMTS) cellular telephone standard, the "3G" Code Division Multiple Access 2000 (CDMA 2000) cellular telephone standard, and the "4G" Long Term Evolution (LTE) cellular telephone standard. Other cellular network access technologies may be used if desired. These cellular network access technologies are merely illustrative.

It may be desirable to test the performance of DUT **10** across the different cellular network access technologies. For example, DUT **10** may be configured to transmit/receive radio-frequency test signals in the GSM frequency bands during a first time period, to transmit/receive radio-frequency test signals in the UMTS frequency bands during a second time period, to transmit/receive radio-frequency test signals in the LTE frequency bands during a third time period, etc. Radio-frequency metrics that are measured across the different cellular telephone standards and frequency bands may include receive power level, power spectral density, error vector magnitude, dynamic range, and other radio-frequency performance metrics.

DUT **10** may be tested in a test system such as test system **11** of FIG. **2**. Test system **11** may include test accessories, computers, network equipment, tester control boxes, cabling, test cells, and other test equipment for conveying radio-frequency test signals and gathering test results. Test system **11** may include multiple test stations such as test stations **13**. There may, for example, be 80 test stations **13** at a given test site. Test system **11** may include any desired number of test stations to achieve desired test throughput.

Each test station **13** may include a test host such as test host **26**, a test unit such as test unit **22**, and a test cell such as test cell **32**. Test host **26** may, for example, be a personal computer or other types of computing equipment.

Test unit (sometimes referred to as a tester) **22** may be a radio communications tester of the type that is sometimes referred to as a call box or a radio communications tester. Test unit **22** need not be capable of supporting protocol-compliant testing (e.g., test unit **22** may lack a full Internet Protocol (IP) stack implementation) and may sometimes be referred to as a non-signaling test unit. Test unit **22** may, for example, be the CMU200 or CMW500 Universal Radio Communication Tester available from Rohde & Schwarz. Test unit **22** may be used to perform radio-frequency non-signaling tests for a

variety of different wireless network access technologies in different radio-frequency communications bands and channels.

Test unit **22** may be operated directly or via computer control (e.g., when test unit **22** receives commands from test host **26**). When operated directly, a user may control test unit **22** by supplying commands directly to the test unit using the user input interface of the test unit. For example, a user may press buttons in a control panel **23** on the test unit while viewing information that is displayed on a display **21** in the test unit. In computer controlled configurations, a test host such as computer **26** (e.g., software running autonomously or semi-autonomously on the computer) may communicate with the test unit (e.g., by sending and receiving data over a wired path **27** or a wireless path between the computer and the test unit).

Test cell **32** may have a cubic structure (six planar walls), a rectangular prism-like structure (six rectangular walls), a pyramid structure (four triangular walls with a rectangular base), or other suitable structures. Test cell **32** may, for example, be a pyramidal-shaped transverse electromagnetic (TEM) cell that serves to isolate DUT **10** from external sources of radiation, interference, and noise so that DUT **10** is being tested in a controlled environment.

DUT **10** may be coupled to test host **26** through wired path **28** (as an example). Connected in this way, test host **26** may send commands over bus **28** to configure DUT **10** to perform desired operations during testing. Test host **26** and DUT **10** may be connected using a Universal Serial Bus (USB) cable, a Universal Asynchronous Receiver/Transmitter (UART) cable, or other types of cabling (e.g., bus **28** may be a USB-based connection, a UART-based connection, or other types of connections).

DUT **10** may be coupled to test unit **22** though a radio-frequency cable such as radio-frequency cable **42**. DUT **10** may include a radio-frequency switch connector **50** interposed in a transmission line path connecting transceiver **6** to antenna **9**. Test cable **42** may have a first terminal **41** that is connected to a corresponding port in test unit **22** and a second terminal **43** that can be connected to switch connector **50**. When cable **42** is coupled to DUT **10** via switch connector **50**, test unit **22** may be configured to perform transceiver testing (e.g., radio-frequency test signals may be conveyed between test unit **22** and transceiver **6**) or antenna testing (e.g., radio-frequency test signals may be conveyed between test unit **22** and antenna **9**). Cable **42** may include a miniature coaxial cable with a diameter of less than 2 mm (e.g., 0.81 mm, 1.13 mm, 1.32 mm, 1.37 mm, etc.), a standard coaxial cable with a diameter of about 2-5 mm, and/or other types of radio-frequency cabling.

Radio-frequency signals may be transmitted in a downlink direction (as indicated by arrow **46**) from tester **22** to DUT **10** through cable **42**. During downlink signal transmission, test host **26** may direct test unit **22** to generate RF test signals at its input/output (I/O) port while DUT **10** may receive corresponding test signals through switch connector **50**. Radio-frequency signals may also be transmitted in an uplink direction (as indicated by arrow **44**) from DUT **10** to tester **22** through cable **42**. During uplink signal transmission, DUT **10** may be configured to generate RF signals using transceiver **6** while test unit **22** may receive the corresponding test signals through its I/O port and may perform desired radio-frequency measurements on the received test signals.

As shown in FIG. **2**, each test station **13** may be connected to computing equipment **36** through line **38**. Computing equipment **36** may include storage equipment on which a database **40** is stored. Test measurements obtained using test unit **22** and test data calculated using DUT **10** may be retrieved by test host **26** to be stored in database **40**. The test setup of FIG. **2** is merely illustrative and is not intended to limit the scope of the present invention. If desired, non-signaling test unit **22** may include more than one port, each of which is coupled to a corresponding DUT **10** in a respective test cell **32**.

FIG. **3** is a timing diagram showing a conventional test method for testing a device under test operating at different cellular network access technologies. From time t**0** to t**1** (e.g., for 5 seconds), a signaling tester (i.e., a test unit that includes a full Internet Protocol stack implementation) may perform initialization operations with a DUT (i.e., the DUT may be waiting for a GSM pilot signal from the tester for synchronization). At time t**1**, the DUT may be synchronized to the tester. From t**1** to t**2** (for 20 seconds), the tester may broadcast test signals in the GSM frequency bands. At time t**2**, the tester may stop broadcasting test signals and the DUT may be desynchronized from the tester.

From time t**2** to t**3** (for 7 seconds), the signaling tester performs initialization operations with the DUT (i.e., to synchronize with DUT by broadcasting UMTS pilot signals). From t**3** to t**4** (for 20 seconds), the tester may broadcast test signals in the UMTS frequency bands. At time t**4**, the tester may stop broadcasting test signals to desynchronize the DUT from the tester.

As shown in the example of FIG. **3**, the idle times during which the DUT and the tester attempt to synchronize with each other may vary and add significant time to the testing process. Moreover, if the DUT fails to receive the pilot (initialization) signal from the tester, test operations will enter fail mode and testing will not be able to proceed properly without test operator intervention.

FIG. **4** is a timing diagram illustrating a test procedure that does not require DUT **10** to be synchronized with test unit **22**, thereby eliminating the idle time periods during which DUT **10** has to wait for initialization signals from the test unit and substantially reducing test time and the probability of a test failure.

In one suitable arrangement of the present invention, DUT **10** may be configured to transmit test signals of a first type during a first time period ΔT**1** (e.g., radio-frequency test signals using network access technology TECH**1**), to transmit test signals of a second type during a second time period ΔT**2** (e.g., radio-frequency test signals using network access technology TECH**2**), to transmit test signals of a third type during a third time period ΔT**3** (e.g., radio-frequency test signals using network access technology TECH**3**), etc. For example, DUT **10** may be configured to output test signals in the GSM frequency bands during the first time period (from t**0** to t**1**), test signals in the CDMA frequency bands during the second time period (from t**1** to t**2**), test signals in the UMTS (also known as wideband-CDMA) frequency bands during the third time period (from t**2** to t**3**), test signals in the LTE frequency bands during the fourth time period, etc. While DUT **10** is transmitting the test signals in the respective frequency bands, test unit **22** may receive the corresponding test signals and performed the desired RF measurements.

In another suitable arrangement of the present invention, test unit **22** may be configured to transmit test signals using TECH**1** during first time period ΔT**1**, to transmit test signals using TECH**2** during second time period ΔT**2**, to transmit test signals using TECH**3** during third time period ΔT**3**, etc. For example, test unit **22** may be configured to generate test signals in the CDMA frequency bands during the first time period, test signals in the GSM frequency bands during the second time period, test signals in the UMTS frequency bands

during the third time period (from t2 to t3), test signals in the EVDO frequency bands during the fourth time period, etc. While test unit **22** is generating the test signals in the respective frequency bands, DUT **10** may receive the corresponding test signals and compute desired RF performance metrics that reflect the quality of received signals. Examples of signal quality measurements that may be made in DUT **10** include bit error rate measurements, signal-to-noise ratio measurements, measurements on the amount of power associated with incoming wireless signals, channel quality measurements based on received signal strength indicator (RSSI) information (RSSI measurements), channel quality measurements based on received signal code power (RSCP) information (RSCP measurements), channel quality measurements based on signal-to-interference ratio (SINR) and signal-to-noise ratio (SNR) information (SINR and SNR measurements), channel quality measurements based on signal quality data such as Ec/Io or Ec/No data (Ec/Io and Ec/No measurements), etc.

In general, the different time periods (e.g., ΔT1, ΔT2, ΔT3, etc.) may be equal or different in duration and any desired network communications technology or standards may be tested during each of the respective time periods.

At least one of DUT **10** and test unit **22** may be loaded with a predetermined test sequence **100** (sometimes referred to as a master sequence list of network access technologies and frequencies to be tested). As shown in FIG. **5**, test sequence **100** may be a table or other types of data structures that contain information identifying an order in which to use each of a plurality of network access technologies to test DUT **10**.

For example, consider a scenario in which DUT **10** is loaded with a test operating system configured to direct DUT **10** output RF test signals based on sequence **100**. During first time period ΔT1, for example, DUT **10** may transmit test signals (T*) at varying output power levels in channel **1** of band **1** associated with a first type of network access technology TECH1 (from time t0 to t1), in channel **2** of band **1** associated with TECH1 (from time t1 to t2), in other channels of band **1** associated with TECH1 (from time t2 to t3), in channel **1** of band **2** associated with TECH1 (from time t3 to t4), in channel **2** of band **2** associated with TECH1 (from time t4 to t5), in other channels of band **2** associated with TECH1 (from time t5 to t6), and in other bands associated of TECH1 (from time t6 to t7).

During second time period ΔT2, DUT **10** may be configured to transmit test signals T* at varying output power levels in channel **1** of band **1** associated with a second type of network access technology TECH2 (from time t7 to t8), in channel **2** of band **1** associated with TECH2 (from time t8 to t9), in other channels of band **1** associated with TECH2 (from time t9 to t10), in channel **1** of band **2** associated with TECH2 (from time t10 to t11), in channel **2** of band **2** associated with TECH1 (from time t11 to t12), in other channels of band **2** associated with TECH2 (from time t12 to t13), and in other bands associated of TECH2 (from time t13 to t14). During testing of each channel, radio-frequency test signals T* may be stepped up or stepped down in power level to test for uplink sensitivity (e.g., the minimum output power level of DUT **10** for which test unit **22** can still receive corresponding test signals properly) or downlink sensitivity (e.g., the minimum output power level of test unit **22** for which DUT **10** can still receive corresponding test signals properly).

Sequence **100** may specify the test time allocated for each channel. For example, test unit **22** may be configured to generate test signals T* for 0.5 seconds in each channel associated with TECH1, for 0.55 seconds in each channel associated with TECH2, or for any desired duration. As a result, the total test time for iterating through sequence **100** is known and predictable. List **100** may include the desired test sequence for testing the performance of DUT **10** across any number of network access technologies and standards. If desired, predetermined test sequence **100** may be loaded into test unit **22** so that test unit **22** generates test signals based on the order specified in sequence **100**.

FIG. **6** is a flow chart of illustrative steps involved configuring DUT **10** to transmit RF test signals during non-signaling test operations. At step **110**, DUT **10** may be placed into test cell **32**. At step **112**, DUT **10** may be loaded with predetermined test sequence **100**. If desired, test unit **22** may also be loaded with sequence **100** so that test unit **22** can anticipate the order and type of test signals it should be expecting during testing. At step **114**, DUT **10** may select a first network access technology for testing based on an initial entry in test sequence **100**. At step **116**, DUT **10** may select a first band/channel to be tested based on the initial entry in test sequence **100**. At step **118**, DUT **10** may then transmit test signals at varying output power levels (T*) in the selected band/channel associated with the selected network access technology.

At step **120**, test unit **22** may receive corresponding test signals and perform desired radio-frequency measurements (e.g., measure receive power level, power spectral density, error vector magnitude, signal-to-noise radio, adjacent channel leakage ratio, frequency response, and other radio-frequency metrics). Processing may loop back to step **116** to test additional channels in the selected band or to test additional bands associated with the selected network access technology, as indicated by path **122**. Processing may loop back to step **114** to test additional network access technologies, as indicated by path **124**.

Upon testing the final entry in test sequence **100**, DUT **10** may be removed from test cell **32** (step **126**). Operations may loop back to step **110** to test additional DUTs, as indicated by path **128**. At step **130**, test data gathered using test unit **22** may be stored locally at test host **26** or stored centrally in database **40**. The test data for each DUT may then be analyzed to determine whether each DUT **10** satisfies design criteria (e.g., pass/fail criteria may be applied to each DUT to determine whether each DUT is to be marked as a passing DUT or a failing DUT).

FIG. **7** is a flow chart of illustrative steps involved configuring test unit **22** to transmit RF test signals during non-signaling test operations. At step **210**, DUT **10** may be placed into test cell **32**. At step **212**, test unit **22** may be loaded with predetermined test sequence **100**. If desired, DUT **10** may also be loaded with sequence **100** so that device **10** can anticipate the order and type of test signals it should be expecting during testing. At step **214**, test unit **22** may select a first network access technology for testing based on an initial entry in test sequence **100**. At step **216**, test unit **22** may select a first band/channel to be tested based on the initial entry in test sequence **100**. At step **218**, test unit **22** may then transmit test signals at varying output power levels (T*) in the selected band/channel associated with the selected network access technology.

At step **220**, DUT **10** may receive corresponding test signals and compute a receive signal strength indicator (RSSI) and other desired RF performance metrics (e.g., RSCP measurements, SINR and SNR measurements, Ec/Io or Ec/No measurements, etc.). DUT **10** may record the computed RSSI internally on its storage circuitry. Processing may loop back to step **216** to test additional channels in the selected band or to test additional bands associated with the selected network access technology, as indicated by path **222**. Processing may

loop back to step **214** to test additional network access technologies, as indicated by path **224**.

Upon testing the final entry in test sequence **100**, DUT **10** may be removed from test cell **32** (step **226**). Operations may loop back to step **212** to test additional DUTs, as indicated by path **228**. At step **230**, RSSI and other test data stored in each DUT **10** may be retrieved by plugging DUT **10** into test host **26**. Test data gathered using this approach may be stored locally at test host **26** or stored centrally in database **40**. The test data for each DUT may then be analyzed to determine whether each DUT **10** satisfies design criteria.

FIGS. **4-7** described herein are merely illustrative and are not intended to limit the scope of the present invention. Non-signaling testing based on a predetermined test sequence (or list) is not limited to testing the performance of DUT **10** across different cellular network access technologies but can be extended to be used for testing the performance of DUT **10** across different WLAN protocols and different modulations schemes.

Consider, for example, a scenario in which at least one of DUT **10** and test unit **22** is loaded with a predetermined test sequence **100** specifying a list of IEEE 802.11 protocols to be tested. In this example, list **100** may specify the order for transmitting test signals using different modulation schemes/data rates associated with IEEE 802.11a during first time period ΔT**1** (e.g., to transmit test signals at data rates of 6, 9, 12, 18, 24, 36, 48, and 54 Mbps), the order for transmitting test signals using different modulation schemes/data rates associated with IEEE 802.11b during second time period ΔT**2** (e.g., to transmit test signals at data rates of 5.5 and 11 Mbps), etc.

The foregoing is merely illustrative of the principles of this invention and various modifications can be made by those skilled in the art without departing from the scope and spirit of the invention. The foregoing embodiments may be implemented individually or in any combination.

What is claimed is:

1. A method of testing a device under test with a test station, the method comprising:

loading at least one of the device under test and the test station with information identifying an order in which to use each of a plurality of network access technologies to test the device under test with the test station; and

using the test station, performing tests on the device under test by conveying radio-frequency test signals of a first type between the device under test and the test station based on the information for a first time period and subsequently conveying radio-frequency test signals of a second type that is different than the first type between the device under test and the test station based on the information for a second time period immediately following the first time period without synchronizing the device under test to the test station.

2. The method defined in claim **1** wherein the test station comprises a test cell, and wherein performing the tests on the device under test comprises performing the tests on the device under test while the device under test is placed in the test cell.

3. The method defined in claim **2** wherein the test station further comprises a test unit coupled to the device under test via a radio-frequency cable, and wherein performing the tests on the device under test comprises generating radio-frequency test signals using each of the plurality of network access technologies with the test unit.

4. The method defined in claim **3** further comprising:

using the device under test, receiving corresponding test signals from the test unit.

5. The method defined in claim **4** wherein performing the tests further comprises:

using the device under test, computing receive signal quality information on the received test signals by obtaining information selected from the group consisting of: received signal strength indicator information, received signal code power information, signal-to-interference ratio, and signal-to-noise ratio information.

6. The method defined in claim **5**, wherein the test station further comprises a test host coupled to the test unit, the method further comprising:

using the test host, retrieving the receive signal quality information from the device under test.

7. The method defined in claim **2** wherein performing the tests on the device under test comprises outputting radio-frequency test signals using each of the plurality of network access technologies with the device under test.

8. The method defined in claim **7**, wherein the test station further comprises a test unit, the method further comprising:

using the test unit, receiving corresponding test signals from the device under test.

9. The method defined in claim **8** wherein performing the tests comprises:

using the test unit, performing radio-frequency test measurements on the received test signals by making at least one measurement selected from the group consisting of: receive signal power, power spectral density, dynamic range, adjacent channel leakage ratio, and error vector magnitude.

10. The method defined in claim **2**, wherein the plurality of network access technologies comprises a plurality of cellular network access technologies.

11. The method defined in claim **1**, wherein loading at least one of the device under test and the test station with information identifying the order in which to use each of the plurality of network access technologies to test the device under test with the test station comprises loading the test station with information identifying the order in which to use each of the plurality of network access technologies to test the device under test with the test station.

12. The method defined in claim **1**, wherein loading at least one of the device under test and the test station with information identifying the order in which to use each of the plurality of network access technologies to test the device under test with the test station comprises loading the device under test with information identifying the order in which to use each of the plurality of network access technologies to test the device under test with the test station.

13. The method defined in claim **1**, wherein there is no idle time period between the first and second time periods.

14. The method defined in claim **1**, wherein the first type of radio-frequency test signals are associated with a first network access technology, and wherein the second type of radio-frequency test signals are associated with a second network access technology that is different than the first network access technology.

15. A method of testing a device under test with a test station, the method comprising:

loading at least one of the device under test and the test station with information identifying an order in which to use each of a plurality of network access technologies to test the device under test with the test station; and

using the test station, performing tests on the device under test by conveying radio-frequency test signals between the device under test and the test station based on the information without synchronizing the device under test to the test station, wherein performing the tests on the

device under test comprises performing the tests on the device under test while the device under test is placed in a transverse electromagnetic cell that isolates the device under test from external interference, wherein the test station further comprises a test unit coupled to the device under test via a radio-frequency cable.

16. The method defined in claim **15**, wherein the test unit is positioned outside of the transverse electromagnetic cell during testing.

17. The method defined in claim **16**, wherein performing the tests on the device under test comprises generating first radio-frequency test signals using a first of the plurality of network access technologies for a first time period and generating second radio-frequency test signals using a second of the plurality of network access technologies for a second time period.

18. The method defined in claim **17**, wherein the second time period immediately follows the first time period.

19. A method of testing a device under test with a test station, the method comprising:

loading at least one of the device under test and the test station with information identifying an order in which to use each of a plurality of network access technologies to test the device under test with the test station; and

using the test station, performing tests on the device under test by conveying radio-frequency test signals between the device under test and the test station based on the information without synchronizing the device under test to the test station, wherein performing the tests on the device under test comprises generating first radio-frequency test signals using a first of the plurality of network access technologies for a first time period and generating second radio-frequency test signals using a second of the plurality of network access technologies for a second time period.

20. The method defined in claim **19**, wherein the second time period immediately follows the first time period.

* * * * *